AN EXPERIMENTAL METHOD FOR THE NVH CHARACTERIZATION OF ELECTRIC MOTORS

Automotive industry is asking for new methodologies to characterize the acoustic emissions of electric motors, since their integration in EVs and Plug-in-Hybrid vehicles is growing. At VIRTUAL VEHICLE we are developing an experimental methodology based on cylindrical Nearfield Acoustical Holography. This allows the evaluation of sound intensity, as well as pressure level and particle velocity. It is suitable for any type of electric motor without knowing either the internal geometry or the material properties.

Need for new NVH methodologies suitable for electric vehicles

Automotive industry is increasingly driven by the need to offer fuel-efficient and eco-friendly mobility. This is mainly achievable by light-weight design, downsizing internal combustion engines, and powertrain electrification and hybridization. Moreover, customers are asking for comfortable and innovative vehicles.

In order to accomplish customer expectations, new NVH approaches are required. They have to deal with new materials, components and powering strategies. In this framework, the prediction and characterization of the noise of electric motors plays a crucial role.

State-of-the-art for electric motor NVH simulation

There are three main approaches to predict or characterize the vibro-acoustic behavior of an electric motor, i.e. analytical, numerical and experimental.

Analytical approaches are usually fast and simple to apply, but their high accuracy is limited to very simple geometries.

Numerical methods (finite and boundary elements) can include fine geometry details, but have as drawback a less flexible workflow and long computational time, especially if high frequencies are included. Moreover, the full knowledge of the material properties is needed. In practice, this turns out to be extremely difficult for coils and lamination pack structures that are typical for some motor types.

Measurements are then the most reliable way to characterize the motor as an airborne sound source. At Area NVH & Friction we are developing an experimental method to characterize the airborne noise emission of electric motors, which are typically almost cylinder-shaped. This characterization method is based on acoustical holography in cylindrical coordinates, i.e. implying the measurement of the sound field in discrete positions on a cylindrical surface around the electric motor [1].

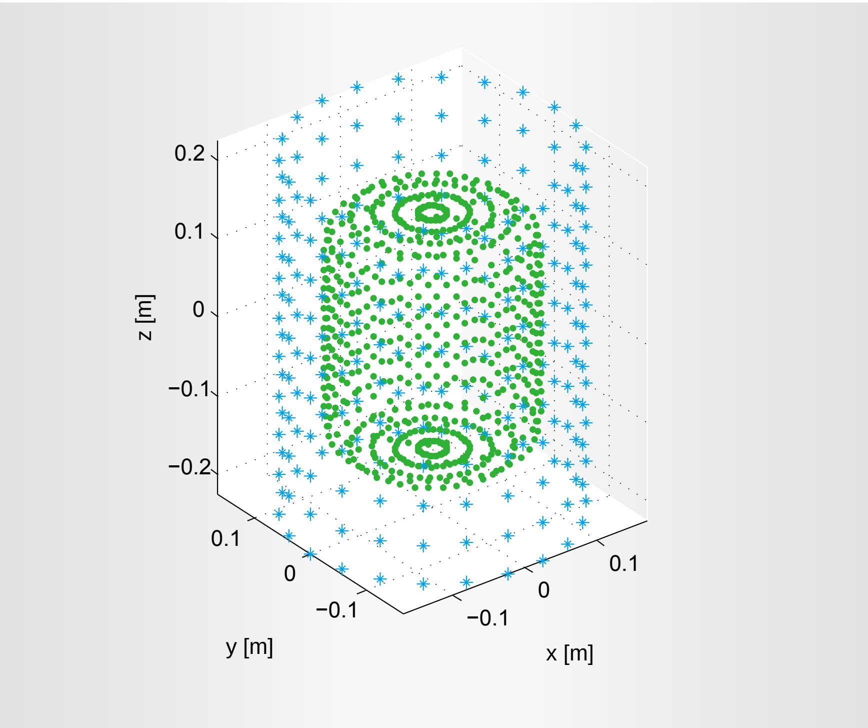

Fig. 1: Electric motor surface (green points) and microphone positions (blue stars)

Proposed methodology

Cylindrical Nearfield Acoustical Holography (NAH) allows an accurate localization and characterization of a source through the back-propagation of a hologram, being thus extremely well suited for cylindrical sources like electric motors.

Cylindrical NAH consists in the following four steps:

1. measurement of the pressure on a grid of points on the hologram surface (i.e. microphone positions)
2. computation of its spectrum through a spatial transform
3. propagation of the spectrum and re-construction of the velocity distribution on the source surface
4. back-transformation to the real space

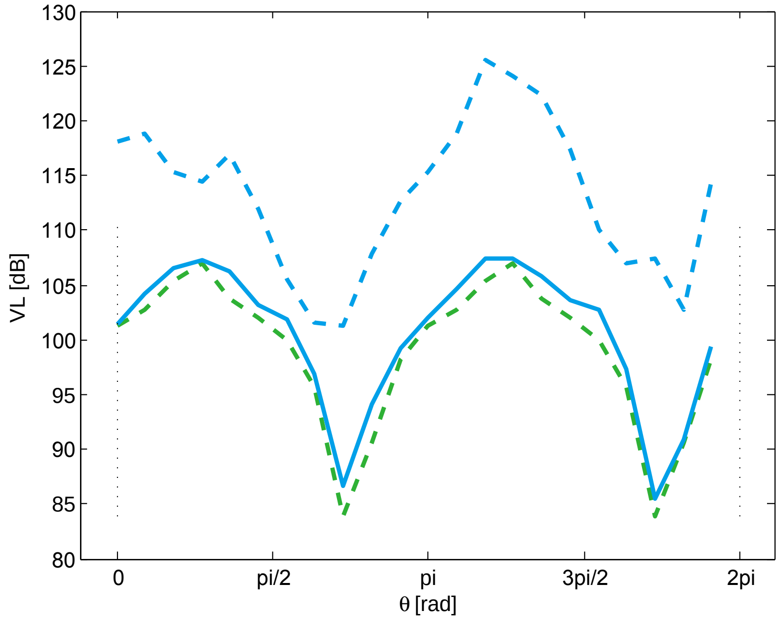

Fig. 2: Comparison of source velocity level (VL) along the circumference: Real velocity (dashed green), NAH not regularized (dashed blue) and NAH regularized (solid blue)

We created a numerical test case to investigate practical aspects of cylindrical holography such as hologram size and possible sources of error. Such simulations allow for designing an effective experimental setup.

Fig. 1 shows the geometry of the test case; the green points represent an acoustic source (motor) while the blue stars are the microphone positions.

NAH is based on an inverse problem, which is sensitive to small input variations (e.g. measurement noise). The robustness of the method is enhanced by filtering the noise components (i.e. regularization).

Fig. 2 shows this regularization effect at a single frequency step along the circumference of the motor and emphasizes the importance of this step for NAH.

Practical aspects of cylindrical holography

Several scenarios have been examined in order to investigate practical aspects of cylindrical holography such as microphone positioning error, background noise, hologram distance, spatial sampling, measurement aperture. Fig. 3 and 4 show the spatially averaged square error (ε) for different hologram

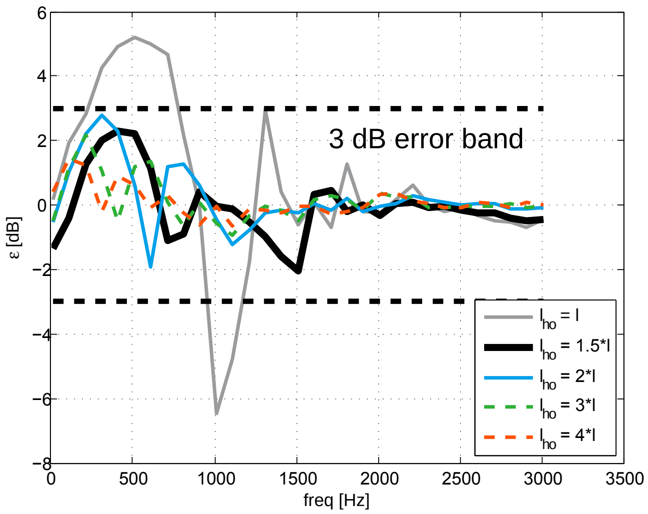

Fig. 3: Spatially averaged square error (ε) for five different hologram lengths

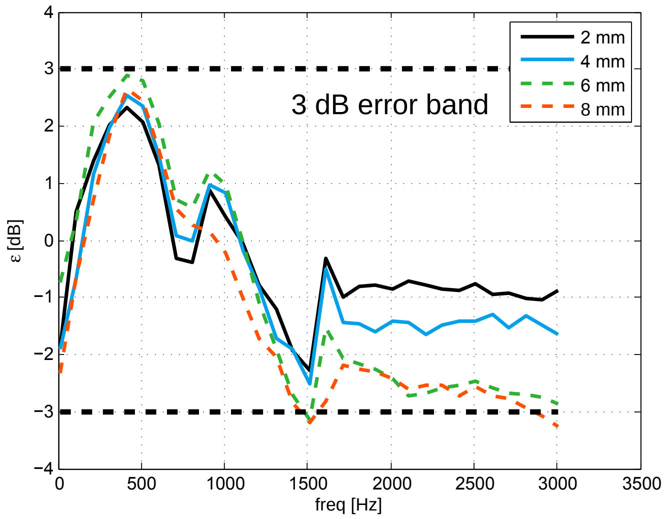

Fig. 4: Spatially averaged square error (ε) with microphone positioning error. The legend refers to the standard deviation of the positioning error (σ_{xyz}).

lengths and microphone positioning errors, respectively. It can be observed in Fig. 3 that for a microphone array of 1.5 times the motor length, the maximum error is within the 3 dB range. Furthermore, the same error band includes the effects of a microphone positioning error of up to 8 mm (Fig. 4).

Conclusions and future work

Cylindrical NAH is an efficient method for the characterization of the acoustical emissions of electric traction motors for next generation green vehicle applications.

Numerical simulations at VIRTUAL VEHICLE have already shown that cylindrical NAH - together with an appropriate regularization scheme - gives accurate results for the reconstruction of the surface velocity of an acoustic source like an electric motor.

Measurement noise can be limited by choosing anechoic test environments. The typical magnitude of this noise does not compromise the results.

Cylindrical holography allows for accurate acoustic characterization also in the presence of sources located on the end caps of the electric motor, such as a cooling fan and bearings.

The frequency range is limited by the number of microphones used. Future work will further investigate the topic in order to understand how many microphones can be excluded without compromising the results.

Free-field measurements on a real electric motor will be performed in an anechoic chamber in order to verify and validate the proposed methodology. ■

References
[1] M. Kirchner, E. Nijman, "Nearfield Acoustical Holography for the characterization of cylindrical sources: practical aspects", in proceedings of 8th International Styrian Noise, Vibration & Harshness Congress (ISNVH 2014), Graz, Austria

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